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Critical Review on Smart Clothing Product Development

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ABSTRACT

Review on historical development of smart clothing implies the most challenges in smart clothing product development, the research approaches under a bias towards technology. The perspectives of design research, physiological considerations, and textile technology are suggested as a framework to consider the multi-disciplinary nature of smart clothing. Current smart clothing products are reviewed based on the issues aroused in the product development process, which is how fashion and technology can coexist in functional clothing. Market segments for smart clothing are re-considered in order to accommodate the user requirements for smart clothing.

Keywords: Smart textiles, textile technology

Introduction

Smart clothing is defined as a new garment feature which can provide interactive reactions by sensing signals, processing information, and actuating the responses (Textile Institute, 2001). Similar terminology such as interactive clothing, intelligent clothing, smart garment, and smart apparel is used interchangeably representing for this type of clothing. This paper will use smart clothing but refer to all.

The purpose of this paper is to conduct a critical review on the smart clothing literature and its developmental issues, focused on how fashion and technology can make harmonious coexistence in a functional apparel product. The multi-disciplinary strategies for smart clothing product development are investigated from the perspectives of design research, physiological considerations, and textile technology. Historical developments and current smart clothing development for diverse market segments is discussed with a brief identification of future research.

Historical Development of Smart Clothing

In 1990s mainly for military use in United States and European countries, smart clothing has prospered in the field of medical and sportswear. Four different stages were distinguished according to historical innovations in research and development (R&D) and in the market (Ariyatum et al., 2005). Significant advances in R&D and in textile and clothing market are depicted chronologically in Table 1.

Table 1. History of Smart Clothing in R&D and Market

1980	1997	2001		2005
	1ST STAGE	**2ND STAGE**	**3RD STAGE**	**4TH STAGE**
R&D	· Steve Mann, Cyberman project · MIT Media Lab., Lizzy project · Sensatex, US military project · Philips Research, Vision of Future project · Bristol Univ., Sensory Fabric project	· Alexandra Fede with Du Pont and Mitsubishi · SoftSwitch, Softswitch technology · Tampere Univ., Intelligent textiles survey · Georgia Tech., Wearable Motherboard · Eleksen, Fabric keyboard	· Infineon Technologies, MP3 player jacket · Tokyo Univ., Transparent Clothes project · Information Society Technologies, Wealthy project	· Konarka Technologies and Textronics, Wearable power generator · Idaho National Laboratory, Solar energy fabric
Smart Textile Market		· SoftSwitch, Fabric Keyboard	· Eleksen, *Logitech Keycase*	· Fibretronic, *ConnectedWear*
Smart Clothing Market		· Philips & Levis, *ICD+ Jacket*	· Sensatex, *Smartshirt* · North Face, Self-heating Jacket · Vivometrics, *LifeShirt* · Burton, *MD Jacket* · Burton, *Amp Jacket* · GapKid, FM radio shirt · Adidas, Self-adapting shoes	· Levis, iPod jean · Zegna, Bluetooth iJacket · Zegna, Solar Jacket · Metallica, *Metallica M4 Jacket* · Oakley, Solar beach tote

Source: Ariyatum, B., Holland, R., Harrison, D., & Kazi, T. (2005). The Future Design Direction of Smart Clothing Development. *Journal of Textile Institute*, 96(4), 199-212.
Fibretronic (n.d.). *Wearables Reaches its 10th Year*. Retrieved August 5, 2009, from http://fibretronic.com

First Stage, 1980s to 1997

The concept of smart clothing has been initiated from the idea of wearable computer. Clothing is selected since it is the most universal interface between human and computer that all are very familiar with. The focus of first stage projects was computing hardware in portable form merely to express advanced technologies. The clothing provided only a platform to support technological devices. Outcomes in this stage were portable rather than wearable and not marketable at all.

Second Stage, 1998 to 2001

The second stage could be characterized by the fashion and textile sectors joined in product development. The number of collaborative projects between electronic and fashion fields rapidly increased. The collaboration between Phillips Electronics and Levi Strauss in 1999 was widely considered to be the very first commercial wearable electronic garment. The applications became more wearable, but they could not meet requirements of the mass market. Most outcomes were still in primitive level because technology was underdeveloped.

Third Stage, 2002 to 2005

While earlier smart clothing focused on technical feasibility, product marketability attracted more interests during this stage. Many development teams realized the needs for inputs from fashion industry and user requirements. The approach has changed from a technical concern to a user-centered one. Miniaturization of electronic devices created more opportunities to achieve higher mobility and comfort, while technical functions kept increasing (Ariyatum & Holland, 2003).

Fourth Stage, 2006 to current

Smart clothing for digital media player approaches to market maturity. It was remarkable that some of high fashion brands jumped into smart clothing development (e.g. Zegna Sport). Intelligence of smart clothing is not limited to manage personal devices the wearers are carrying. Previously, the flow of information was from users to the environment, but currently it became reverse or both directions. Wearable technology tries to accept, analyze, and transform information from environment to assist the user. For example, smart clothing attracts great interests to create renewable and wearable energy sources from solar power or kinetic energy of the wearer.

Framework

Smart clothing is understood as an object of interdisciplinary research from different disciplines. It is important to review how researchers view smart clothing as research objects and how different disciplines define the intelligence integrated into the products on the basis of different research paradigms. According to Textile Institute (2006c), smart clothing is located on the intersectional province of design research, physiology, and textile technology (Figure 1).

Design research focuses on product development issues and includes the objectives of environment and communication. The product development process is important because redesign costs become higher as the process goes closer to production, while costs to change designs remain lower in development stages. Physiological concerns are related closely to human factors such as sensory comfort and mobility. Comfort includes psychological and physiological aspects. Psychological aspects will be put aside in this paper, and human body and its reaction to environmental changes will be discussed with the physiological considerations. Lastly, textile technology takes care of the materials, which are e-textiles and the incorporation with the clothing. Compatibility of dissimilar properties in technology and clothing is the most challenge from textile point of view. The multi-disciplinary nature of smart clothing is related to the integration of design research, physiology, and textile technology as illustrated in Figure 1.

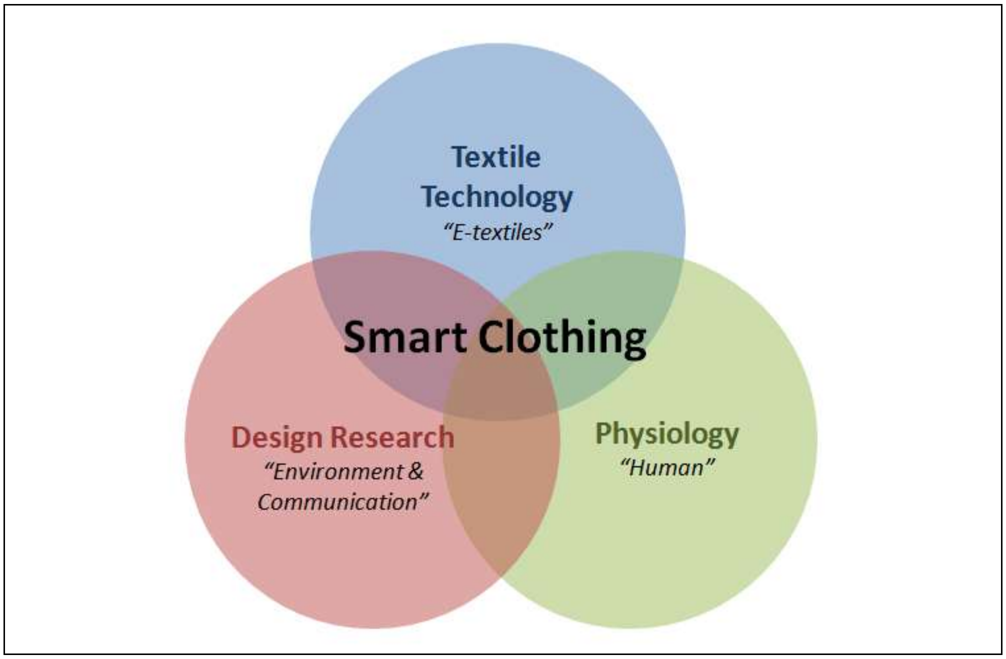


Figure 1. Multidisciplinary Approach to Smart Clothing

Source: Textile Institute (2006c). *Intelligent Textiles and Clothing* (Mattila, H. Ed.), Florid: CRC Press.

Design Research

In business and engineering, new product development is the creation of physical products or services to respond to customer needs (Ulrich & Eppinger, 2004). The ideas are transformed into reality through the product development process. It is a set of sequential activities and tasks which translate customer needs into product design. Design is creative, but the process leading to successful designs can be made predictable and transparent (Regan et al., 1998; Watkins, 1988). Research on the product development process aims to maximize the effectiveness of successful product development by increasing reliability of actions and decisions earlier in the development process (Regan et al., 1998). Previously suggested models go through the five steps of idea generation, design, prototype development, evaluation & design refinement, and production planning as illustrated in Figure 2.

Product Development Process

Most systematic product development approaches are based on engineering design process theory (Lewis & Samuel, 1989; Figure 2). It takes seven steps to identify users' needs and develop a product to meet identified needs. On the other hand, Crawford and Di Benedetto (2003) presented very managerial point of view. The process begins with business opportunity and existence of sales potential rather than the problem recognition in their new product development process model (Figure 2). Other developmental and evaluative steps follow the business plan established at the early stage.

According to Crawford & Di Benedetto (2003) and DeJonge (1984), product development processes are overlapped and iterative. A loop structure is created by going back to any of previous steps until completion of a whole problem as well as a series of smaller associated problems. The activities shown in Figure 2 are not merely sequential, but overlapping. Each stage begins before the previous one is completely finished. Therefore, the designers should keep all the procedures in mind throughout the whole process.

Clothing Product Development Process

Clothing product development process follows the new product development process in general. According to Regan et al. (1998), the clothing design process is congruous with engineering design process theory. The desire of people to look beautiful and updated in fashion is a big opportunity for apparel manufacturers and design problems are found in staying up to date with fashion trends. The characteristics of clothing products and fashion industry should be addressed to understand the process.

Clothing product development process is highly affected by the size and nature of the firm and its fashion orientation (Glock & Kunz, 2005). The size of an apparel firm affects product volume and the number of people with product development responsibilities. For small firms, still common in the apparel business, product development tasks may be performed in less systematic ways, for example, by the owner or single designer; whereas designers in large firms are the part of the product development team. The stronger the fashion focuses of the product, the more important the designers' influence in the product development process (Glock & Kunz, 2005). Most apparel firms place relatively heavy emphasis on originality and fashion-forward products. According to Regan et al. (1998), clothing products are characterized 80% by aesthetics and 20% by function; whereas, other products are 80% function and 20% aesthetics. However, even aesthetics is not solely intuitive. It can be achieved by taking the productive development process step by step.

Gaskill's model (1992) put more value on merchandising and market-oriented product compared to engineering design process. Wickett et al. (1999) expanded the Gaskill's model. The focus is shifted from market availability to product feasibility. The stages after final adoption were specified and named as technical development, which includes fit/style perfecting, production pattern making, material/garment specification, and sourcing processes. These were expected to increase overall efficiency during the production.

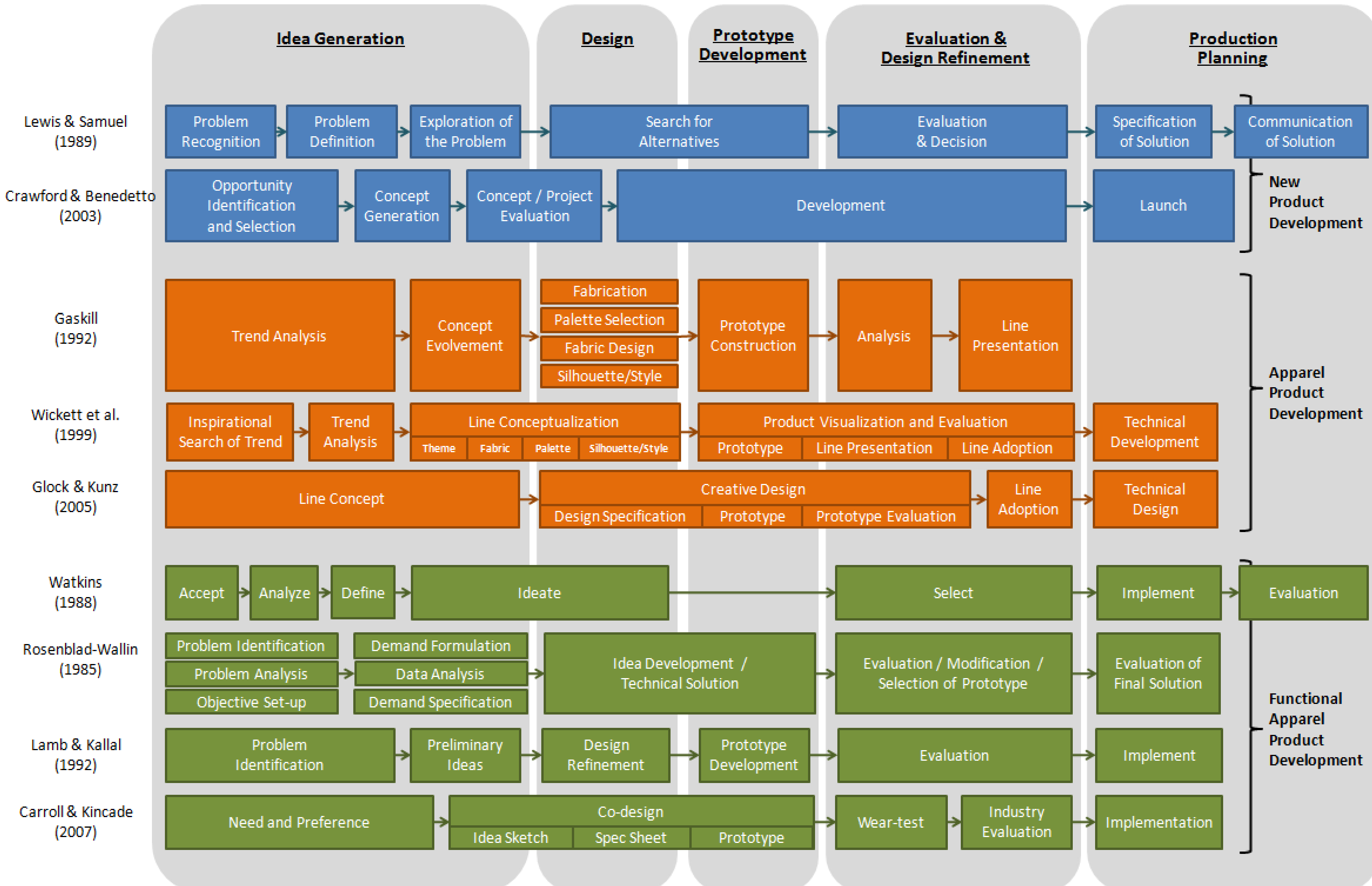
Glock & Kunz (2005) also have several factors in common with Gaskill's model. Activities involved in creating clothing products within an apparel manufacturing company were listed out and named Merchandising Taxonomy. Merchandising process consists of line planning, line development, and production. Products are developed through the line development stage which includes line concept, creative design, line adoption, and technical design processes. Clothing product development models found from previous researches are summarized on the orange-colored rows in Figure 2.

Functional Clothing Product Development Process

Functional textile and clothing development has prevailed in the field of sportswear and sporting equipment (Textile Institute, 2005; O'Mahony & Braddock, 2002). Functional clothing provides special functionality to the wearer such as protection or assistance which the conventional garment cannot. It is worn by the specific group of people at special occasion (e.g. fire-fighting, space, sports).

The overall process for functional clothing is not very distinguishable from the typical clothing design framework. However, the information-gathering stage focusing on the needs and preferences of the target customer has much more emphasis in functional design, as shown in the following studies. Previous product development frameworks for functional clothing are depicted on last four green rows in Figure 2.

Watkins (1988) proposed seven steps to successful design for functional clothing (Figure 2). DeJonge (1984) put much importance on early development stages in which initial requests are made for a design solution (Labat & Sokolowski, 1999). If the problems are thoroughly accepted, analyzed, and defined in the early stages, the rest of the process becomes more productive. Many new ideas are generated and then sorted out to pick the most promising one. Future research (Carroll & Kincade, 2007; Lamb & Kallal, 1992) suggests that prototype construction and evaluation to explore the feasibility of potential solutions.


Idea Generation
Design
Prototype Development
Evaluation & Design Refinement
Production Planning
Lewis & Samuel (1989)
Problem Recognition
Problem Definition
Exploration of the Problem
Search for Alternatives
Evaluation & Decision
Specification of Solution
Communication of Solution
Crawford & Benedetto (2003)
Opportunity Identification and Selection
Concept Generation
Concept / Project Evaluation
Development
Launch
New Product Development
Gaskill (1992)
Trend Analysis
Concept Evolvement
Fabrication
Palette Selection
Fabric Design
Silhouette/Style
Prototype Construction
Analysis
Line Presentation
Wickett et al. (1999)
Inspirational Search of Trend
Trend Analysis
Line Conceptualization
Theme
Fabric
Palette
Silhouette/Style
Product Visualization and Evaluation
Prototype
Line Presentation
Line Adoption
Technical Development
Glock & Kunz (2005)
Line Concept
Creative Design
Design Specification
Prototype
Prototype Evaluation
Line Adoption
Technical Design
Apparel Product Development
Watkins (1988)
Accept
Analyze
Define
Ideate
Select
Implement
Evaluation
Rosenblad-Wallin (1985)
Problem Identification
Problem Analysis
Objective Set-up
Demand Formulation
Data Analysis
Demand Specification
Idea Development / Technical Solution
Evaluation / Modification / Selection of Prototype
Evaluation of Final Solution
Lamb & Kallal (1992)
Problem Identification
Preliminary Ideas
Design Refinement
Prototype Development
Evaluation
Implement
Carroll & Kincade (2007)
Need and Preference
Co-design
Idea Sketch
Spec Sheet
Prototype
Wear-test
Industry Evaluation
Implementation
Functional Apparel Product Development

M

Figure 2. Product Development Processes

Source: Lewis, W. & Samuel, A. (1989). *Fundamentals of Engineering Design*. New York: Prentice Hall.

Crawford, M. & Di Benedetto, A. (2003). *New Products Management*. New York: McGraw-Hill.

Gaskill, L. (1992). Toward a Model of Retail Product Development: A Case Study Analysis. *Clothing and Textiles Research Journal*, 10(4), 17-24.

Wickett, J., Gaskill, L. & Damhorst, M. (1999). Apparel Retail Product Development: Model Testing and Expansion. *Clothing and Textiles Research Journal*, 17(1), 21-35.

Glock, R. & Kunz, G. (2005). Apparel Manufacturing Sewn Product Analysis, Macmillan: New York, USA.

Watkins, S. (1988). Using the Design Process to Teach Functional Apparel Design. *Clothing and Textiles Research Journal*, 7(1), 10-14.

Rosenblad-Wallin, E. (1985). User-oriented Product Development Applied to Functional Clothing Design. *Applied Ergonomics*, 16, 279-287.

Lamb, J. & Kallal, M. (1992). A Conceptual Framework for Apparel Design. *Clothing and Textile Research Journal*, 10(2), 42-47.

Carroll, K. & Kincade, D. (2007). Inclusive Design in Apparel Product Development for Working Women with Physical Disabilities. *Family and Consumer Sciences Research Journal*, 35(4), 289-315.

Functional clothing development process is in contrast with conventional clothing development in terms of the location of core stages. Generally, clothing products start with market needs and go through product-oriented processes where critical decisions are made in design and evaluation phase (Glock & Kunz, 2005; Wickett et al., 1999; Gaskill, 1992; Figure 2). Determination of physical specifications of the products (e.g. colors, fabrics, silhouette, and style) differentiates conventional clothing product development. The consumer seeks a benefit that will give satisfaction, but is not the center of the process. Satisfaction is confirmed not by wear-testing, but by the second purchase they might have (Resenblad-Wallin, 1985).

On the other hand, functional clothing development can be characterized by user-oriented processes. Heavy work load is put on the initial research phase when the users and use-situation are investigated. Studying consumer preference between functional needs and aesthetic desires played the most important role (Carroll & Kincade, 2007; McCann et al., 2005; Rosenblad-Wallin, 1985; DeJonge, 1984). The consumers wear functional clothing because they have special needs, but they do not want to be limited in other needs such as comfort and aesthetics (Lamb & Kallal, 1992).

User Analysis

The user value for clothing comprises functional and symbolic attributes (Rosenblad-Wallin, 1985). Functional value is to provide protection and comfort, while symbolic value is the impression the wearer gives to other people by exterior appearance. FEA consumer needs model (Lamb & Kallal, 1992) which consists of functional, expressive, and aesthetic considerations. Functional considerations are equivalent to the functional attributes. Expressive considerations refer to communicative symbolic aspects of dress, while aesthetic considerations take care of human desire for beauty. Functional, expressive, and aesthetic needs vary with the target consumers and their cultural basis and none of these aspects can be neglected in functional clothing development.

Depending on the different background researchers are mainly oriented from, the user analysis put focuses on specific concerns. Park and Jayaraman (2003) identified the key user requirements during Smartshirt ™ development process from the perspective of functionality, usability, wearability, durability, maintainability, and affordability. Their prior concerns were based on function-related requirements and aesthetic consideration was fairly neglected. The approach of McCann et al. (2005) to view smart clothing was very apparel-oriented. They categorized the end-user needs for smart clothing into four: demands of the body, demands of the end-use activity, demands of the culture, and aesthetic considerations. Demands of the body focus on human physiology to feel good. Demands of end-use activity and culture are dealing with the issues of being physically and socially appropriate, respectively. Aesthetic considerations are the application of the elements and principles of design into an harmonious outcome.

In order to accommodate user requirements during the functional clothing development process, Carroll and Kincade (2007) introduced a co-design phase where designers and consumers share their ideas to design a product. The consumers are directly involved throughout the product development process. The participation in the actual design process helps consumers communicate with designers and manufacturers efficiently and their needs can be reflected on the products.

Application for Smart Clothing

The concept of smart clothing can be understood within the scope of functional clothing. Functional clothing is worn for special functional needs such as protection from extreme environments or accomplishment of high-tech performance. Smart clothing integrates functional clothing design and portable technology and can be regarded as one of the functional clothing in which technological functions are automatically activated and deactivated.

Although innumerable research projects and products were developed in practice, there has been no theoretical guideline established for smart clothing product development. If we approach smart clothing from the functional clothing point of view, the pending issue is how to position the new component, the integrated technology, into the process. This issue will be covered later in Fashion and Technology.

Physiological Consideration

Smart clothing should be developed on the physiological basis in order to implement the smart applications which maintain the comfort and usability of ordinary clothes. The demands of the body were highlighted as essential design considerations for functional clothing. According to McCann et al. (1999), the demands of the body were protection, anthropometry, ergonomic of movement, thermo-physiological regulation, and psychological considerations. Bryson (2007) addressed water regulation, thermal regulation, and physical sensation. Critical physiological concerns for smart clothing found in literature can be joined together into the issues of thermal comfort (heat and moisture regulation), tactile comfort (physical sensation) and mobility (movement, fit, and size) issues.

Thermal Comfort

The body constantly generates heat from the metabolism and loses this heat to the environment. A balance must be maintained between the rates of heat production and heat loss (Textile Institute, 2006a). Discomfort becomes apparent when the body feels too hot or too cold. Thermal balance is closely related to the transport or conservation of heat and moisture throughout the garment system (Barker, 2002). Thermal comfort of the clothing has been investigated in terms of thermal protection. The most functional clothing in this field of research is firefighters' turnout gear (Barker et al., 2006). Zone selection, thermal profiles, and physiological thermal modeling were important to develop the thermal protective clothing (Koscheyev et al., 2000).

Generally, thermal comfort can be calculated from the measure of characteristics of the clothing, the climate conditions, and the level of physical activity (Textile Institute, 2006b). For smart clothing application, additional factors needs to be involved. The heat generated by electronics may break thermal equilibrium in a garment system and damage to other technological elements if auxiliary cooling does not take place. A printed circuit board made up of layer of impermeable resin prevents evaporative heat loss and accumulates trapped heat. Trapped moisture may cause a short circuit or corrode interconnections (Dunne et al., 2005). Both physical impacts of functionality on the human body and the impacts of human physiological reaction on technology should be taken into account.

Tactile Comfort

The interaction between fabric and human skin will stimulate various sensory receptors on the skin and may cause uncomfortable feelings such as tickle, itch, prickle, and abrasion of the skin (Textile Institute, 2006a). For the clothing, overall tactile feeling is related more to pressure comfort which includes heaviness and tightness rather than prickliness, itchiness, and roughness (Textile Institute, 2006a; Barker, 2002).

A technological component, while ever decreasing in dimension and weight, adds extra weight and pressure on a human body (Dunne et al., 2005). Since the level of tolerable pressure varies at different positions on the body, careful distribution of technological component is required when the smart clothing is developed. If a specific body area is exposed to excessive loads, there occurs muscle fatigue. In addition, since metabolic rate increases when the body tries to work against the heavy and stiff clothing, unwanted heat production may also occur. Continuous high pressure may develop of various tissue lesions, such as pressure sores and ulcers (Textile Institute, 2006a).

Mobility

Mobility issues have attracted great concerns in performance sportswear such as swimsuit and diving suit (O'Mahony & Braddock, 2002). The ease of movement is dependent on garment design and the relative size between body and clothing. High stretch fabrics have provided opportunities for the functional clothing to accommodate both tight-fitting and body movement (Textile Institute, 2006a).

Mobility within clothing is reduced as technological function increases. If wearable technology incorporates bulky and stiff areas, they must be situated at specific locations on the body in order to avoid the abrasion and preserve the mobility. Dunne et al. (2005) suggested the places where volume and stiffness already exists; shoulder, upper back, and abdomen. The selection of location varies according to wearer's gender or age and technical functionality. For example, upper chest of the male and upper back of the young is a planar surface, while it is not true for the opposite groups (Dunne et al., 2005). This may go more challengeable when technological functionality depends on specific body area in order to operate as intended, such as sensors or actuators.

Smart clothing designers are accustomed to taking into account the interactions between human physiological reactions and physical characteristics of garment. The wearer should not be limited in comfort and mobility as a result of intelligent adaptation in clothing (Bryson, 2007; Dunne et al., 2005; McCann et al., 2005; Koscheyev, 2000). At the same time, technological devices must not be damaged or lose the efficiency by any external interruption (e.g. posture or movement) and body wastes (e.g. sweat or heat) that the wear creates.

Textile Technology

Functional forms do not necessarily emerge as a consequence of pleasing the aesthetic preferences of the users. Rather, it is natural that the design to satisfy functional demands inherently conflicts with the aesthetic demands (Bryson, 2007). For example, functional preference for extended power supply of portable devices such as laptop computers or cell phones must result in huge and awkward looking batteries additionally attached. Unfortunately, with the current advances in technology, it seems hard to fully satisfy both functional and aesthetic worlds. This can be regarded as the matter of choosing between practical usefulness and aesthetic desirableness. As many other new products, the developmental issue, whether it is style or function oriented, is continually challenged when designing a new smart clothing (Powell & Cassill, 2006).

Fashion and Technology

The apparel is one of the products highly appealing to aesthetic preference of the user. Aesthetically pleasing design is an integral part of the success in fashion and apparel industry. Although technical aspects have the strong influences in smart clothing development, we cannot expect fashion industry to adapt itself to technology. Before we start designing smart clothing, we have to ask to ourselves which should be a decisive factor, form (style or fashion) or function (technical performance or technology).

For most cases, consumers want to enjoy most advanced technology without losing their fashion sense. Products designed awkward in style simply cannot attract users' attention. For example, walking aids should not look like something that people with a walking problem use. It needs to be designed as if it were not there or at least it were a part of fashionable accessories such as shoes or handbags (Murata, 2008). Although some people may want to hide technology out of their sight, others may want to give visible forms to the technology, simply in order to show other people that those functions are there.

Sometimes, the functional form can survive in an aesthetic purpose even after its practical function is taken away. Sports shoes, developed from conventional footwear, have established their own look as a fashion and spread to affect other casual and even formal footwear. Now, many shoes are designed similar to sports shoes, though the people who wear them may never actually indulge in any sporting activity (Marzano et al., 2000). Fashion designers borrow the high-tech textiles originally intended for extreme sports and use them for ready-to-wear and haute couture. Extreme sportswear look can be found in many fashionable wardrobes as designers consider the look of the new sport clothing modern and glamorous (O'Mahony & Braddock, 2002).

Degree of Technology Integration

Until every part of technology can be made out of textile material without any functional limitation, technical components cannot b completely integrated into the clothes. To empower the appearance, technology must be simplified and invisible as much as it can. If technology is not invisible, it should have an attractive appearance and become fashionable accessories of the clothing such as a button or a zipper. Degree of body and technology integration has been classified into three categories shown in Table 2.

Table 2. Degree of Technology Integration

Degree	Type		Description
High	Implanted		Such as implants or tattoos
	Wearable	Integration	Technology is integrated into the fabric as an intrinsic part
		Embedment	Technology is physically attached or embedded into clothing or textile substrates
		Contents	Clothing is the container for technology
Low	Handheld		Such as mobile devices

Source: Seymour, S. (2008). *Fashionable Technology: The intersection of Design, Fashion, Science, and Technology*. Wien: Springer Wien New York.

Degree of integration is highly dependent on the demands for expressiveness and functionality of smart clothing. Expressiveness is based on the socio-cultural and psychological aspects of the dress, while functionality is oriented from the practical assistance embedded technology can provide to the wearers. Seymour (2008) defined three levels of expressiveness versus functionality in smart clothing and they are shown in Table 3. Similarly, Ariyatum et al. (2005) located sportswear products on the middle point of purchasing criteria spectrum constructed with the bipolar values of practical function and emotional fashion attributes. This position is suggested to be appropriate for smart clothing (Ariyatum et al., 2005). Smart clothing must address a practical function as do electronic devices, and attractive design and emotional values as do fashion clothes.

Table 3. Level of Expressiveness versus Functionality

	Level	Description	Example
Expressiveness	1	The fashionable wearables are implements for personal expression and the functionality is less important.	High Fashion
	2	The fashionable wearables have a defined function and some need to be stylish.	Sportswear
Functionality	3	The functionality is the focal point. The necessity for personal expression is limited by strict pre-defined functionalities and restrictions.	Workwear

Source: Seymour, S. (2008). *Fashionable Technology: The intersection of Design, Fashion, Science, and Technology*. Wien: Springer Wien New York.

Current Development of Smart Clothing

According to Ariyatum & Holland (2003), the major applications of smart clothing can be categorized into military, medical, communication, entertainment and sports/recreation. The growth rates vary dramatically by the application segment. The highest growth is expected in consumer entertainment, medical status monitoring, and military applications. Detailed information on US market segments provided by British Chambers of Commerce (BCC) is shown in Figure 3.

Two of the four applications will be studied in terms that which products are developed in the market: entertainment and biomedical segments. These are most promising field which take two third of overall smart clothing market.

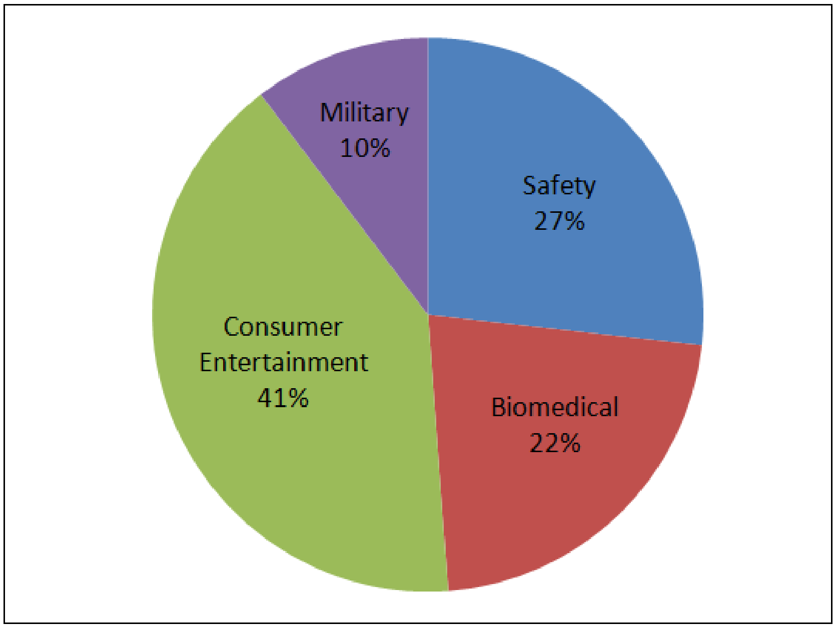


Figure 3. US Smart Clothing Market by Segment

Source: British Chambers of Commerce, 2008

Smart Clothing for Medical Use

Firstly designed for military purpose, Smartshirt™ by Sensatex uses plastic optical fiber transferring signals at a regular interval and detects the injuries such as gunshots of a soldier in the battlefield. Later on, this technology is transferred for civilian use to accommodate smart wear for medical and sports purpose. Vivometrics also released the first Lifeshirt™ for emergency-service workers and they expanded the market to general consumer after adjusting the manufacturing cost. For most health monitoring smart clothing, the processor unit acquires data from the sensors and transmit them to the remote medical center in real-time through wireless network. They made remote patient monitoring possible.

Degree of technology integration in Smartshirt™, Lifeshirt™, and Wealthy is summarized in Table 4 for their major functionalities. All need additional equipments for measuring and processing. They are not practical for unnoticeable health monitoring. Only primitive technologies such as optical fibers and electrocardiogram electrodes are integrated, while other complicated technologies such processor and sensors are at embedment or contents level.

Table 4. Integration of Technology for Medical Use

	Technology	Function	Degree of Integration	Integration Method
Smart Shirt™	Optical fiber	Signal transfer	Integration	Woven
	Processor	Data transmission	Embedment	Pocket
Life Shirt™	Electrode	Cardiopulmonary signal	Contents	Inserted in slit
	Respiband	Respiratory data	Embedment	Sandwiched in between linings
	Processor	Data transmission	Handheld	
Wealthy	Electrode	Electrocardiogram	Integration	Knitted
	Piezoresistive sensor	Respiratory data Body movement	Contents	Pocket
	Temperature sensor	Skin temperature	Embedment	Sewn on lining
	Processor	Data transmission	Contents	Pocket

Author: Suh, M. (2009)

Smart Clothing for Entertainment

For the smart clothing with built-in MP3 player controller, the market is approaching to maturity. A lot of recent commercial products are based on Fibretronic Embedded Textile Devices (Figure 4). It is created by embedding micro printed circuit board within the structure of fabrics and bonding it for permanent fixation. Wires for signal transfer were woven on the strap and supposed to be connected to external MP3 players. The controllers are set in forms of keypad or joystick (Figure 4) allowing the functions such play/pause and volume control. The decreasing cost encouraged its widespread adoption and availability. In 2009, Fibretronic released a developer kit of their keypad technology for DIY application. This kit is developed to fit to any jackets or bags allowing everybody to create their own smart clothing.

Smart clothing represents the future of both the textile and clothing industry and electronic industry. As the convergence between these two industries brings large opportunities and challenges, it draws great attention and investment from different fields. Currently, however, none of smart clothing applications is considered a full integration of high technology and fashion design, since most research attempts are focusing on solving technical problems such as integrating microchip and processors into the clothing and overcoming wash and care issues.

(a) (b)

Figure 4. Fibretronic Embedded Textile Devices: (a) keypad, (b) joystick

Source: Fibretronic (n.d.) from http://fibretronic.com

Conclusion

Smart clothing has opened a new lifestyle to the consumers and business revolution to the industry. We will not only have to decide which jackets or pants would be matched together but also have to customize those garments in terms of the functionalities that we think necessary during the day (Marzano et al., 2000). For the first time, an industry that has traditionally been dominated by fashion and style engaged itself in another totally different industry, the electronics industry.

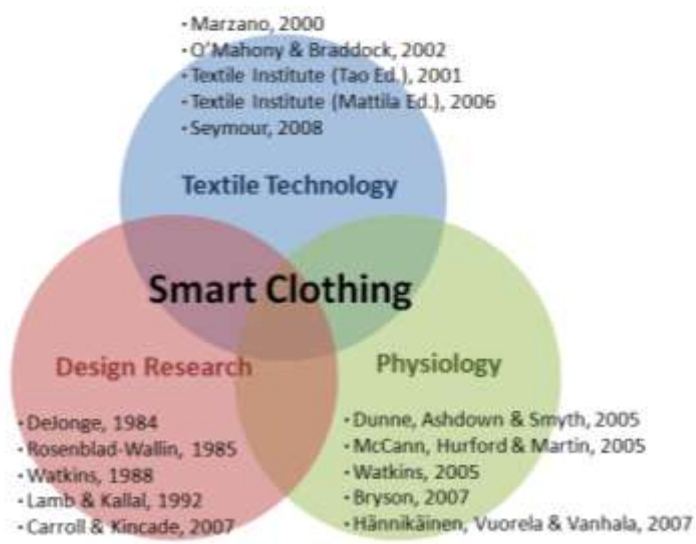


Figure 5. Key Researches from Different Disciplinary Approaches

Author: Suh, M. (2009)

Smart clothing is defined to locate in the intersectional area of design research, physiology and textile technology. Historical and current development of smart clothing product is summarized and developmental issues related to smart clothing are reviewed from the perspective of each discipline. The key researches for each field are listed in Figure 5. Successful product development for smart clothing is possible only when these researches are integrated to work together.

Current market segment divided by technical functionalities (Figure 6a) reflects that how we have been product-oriented when we consider the smart clothing so far. Through the literature, we saw that user analysis is so important for functional apparel product development. Smart clothing market segment needs to be re-considered according to the target users as suggested in Figure 6b. The requirement of expressiveness and functionality can be understood clearly if smart clothing market takes the user-oriented viewpoints.

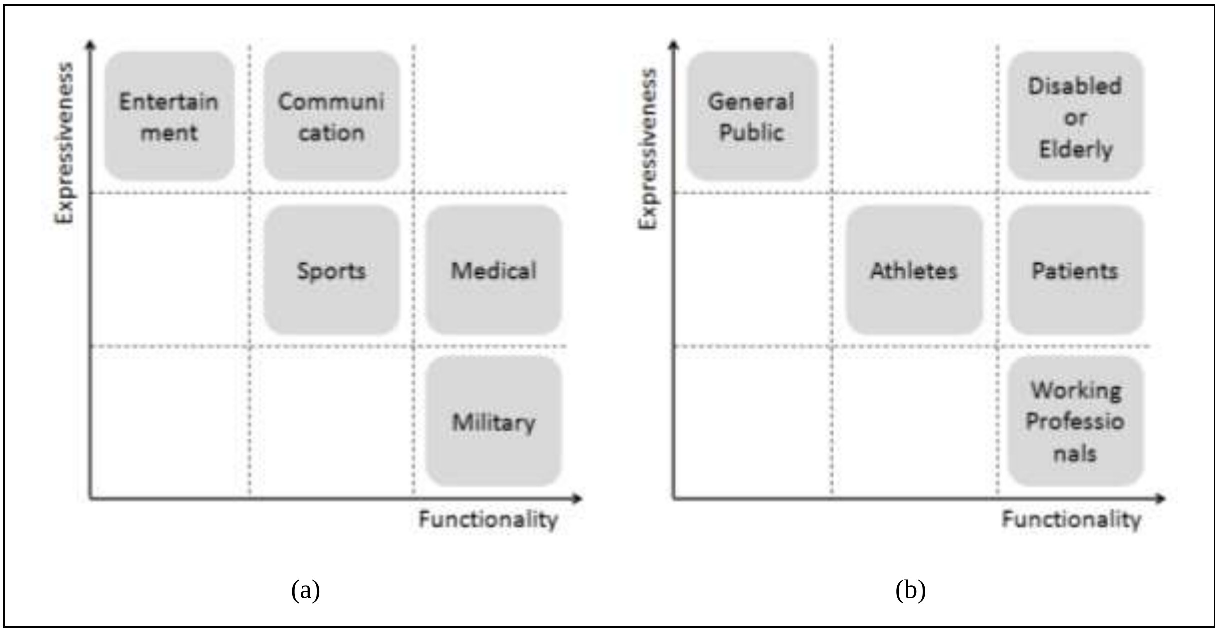


Figure 6. Mapping of Smart Clothing Market Segments: (a) by product-oriented segment, (b) by user-oriented segment

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